DESIGNING SYSTEMS TO BIOLOGICALLY TREAT PERCHLORATE-CONTAMINATED WATER

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Introduction

Perchlorate (ClO_4^-) contamination of groundwater may affect the drinking water supplies of at least 12 million people in the US. Perchlorate is used as an oxidizer in solid missile and rocket fuel (up to 70% by weight), in automobile air bag inflation systems, and is present in some lawn fertilizers (<0.84%) (Urbansky 1998, Susurla et al. 1999). Perchlorate is a human health concern due to its ability at high doses to interfere with iodine uptake and the ability of the thyroid to regulate hormones and metabolism. There is no federal drinking water standard for perchlorate, but many states have adopted an interim provisional drinking water standard of 18 ppb.

Unlike many other highly oxidized compounds, perchlorate is extremely stable in water. For example, perchlorate does not react with common reductants (iron metal, thiosulfate, sulfate, sulfite, iodide and ferrous ions) and it has long half lives even with ordinarily reactive metals such as Ru^{+2} (3.6 d), Ti^{+3} (0.83 yr), and V^{+2} (11.3 yr) (Espensen 1997); even at a pH of 4, the half-life of perchlorate with Ti^{+3} in the absence of air is 50 days (Urbansky 1998).Other chloro-oxy anions have more variable reactivity. Chlorite (ClO_2^-) can be removed with ferrous iron or with sulfur dioxide-sulfide compounds (Gorden et al. 1990, Iatrou and Knocke 1992). More oxidized halo-oxy anions such as chlorate (ClO_3^-) are stable under those same conditions. Another common inorganic ion in drinking water, nitrate, can be reduced using zero valent iron (Siantar et al. 1997).

Microbiological reduction of perchlorate can be quite rapid (Logan 1998). Perchlorate is used as an electron acceptor by a number of bacterial strains under anoxic conditions. We have been conducting experiments using three different fixed-film biological treatment processes to determine their feasibility for drinking water treatment. These systems are: a packed bed (slow sand filter) amended with soluble microbial carbon sources (acetate or ethanol); a membrane (lactate-fed) reactor that keeps the water separated from the microbial consortium (experiments conducted by Dr. Jaci Batista at the University of Nevada, Las Vegas); and a hydrogen gas fed four-phase (hydrogen gas, water, biofilm, and support media), unsaturated trickle-type packed column.

Research Findings

For over 155 days in the acetate-fed, packed bed reactor, perchlorate was reduced from 20 ppm to below the detection limit (<4 ppb) at detention times as low as 13 minutes (Logan and Kim 1998; Logan et al. 1999b). In the hydrogen-oxidizing reactor, detention times were only 1.1 to

1.3 minutes at the same hydraulic loading rate (0.45 cm/min) due to unsaturated flow conditions in the reactor. An average of 40% of the perchlorate was removed in the hydrogen gas reactor at a feed concentration of 0.72 ppm over the 140 day period (Logan et al. 1999a). Overall perchlorate removal kinetics in the membrane reactor are still being evaluated.

In order to study in greater detail perchlorate-degradation kinetics, we obtained isolates of hydrogen-oxidizing and acetate-oxidizing perchlorate-respiring bacteria. Batch kinetic tests produced perchlorate half saturation constants in the range of 12-27 ppm, indicating that perchlorate removal rates at low concentrations (ppb levels) would be first order. The growth rates of two perchlorate-respiring isolates were found to be very rapid. Minimum doubling times using chlorate, perchlorate and oxygen ranged from 2.5 to 5 hours using acetate as the electron donor. Cell yields were nearly constant regardless of the electron acceptor used.

Implications for Reactor Design

These laboratory experiments demonstrate that all three of the biological treatment systems are technically feasible technologies for treatment of perchlorate contaminated water. The actual reactor that should be used for drinking water treatment, however, may depend at least as much on social as technical issues. For example, it is well known that biological treatment of nitrate in drinking water is both feasible and economical, but there is only one known site in the United States where it is currently used (Coyle, OK; www.nitrateremoval.com). Acetate is a relatively inexpensive carbon source, but its use may not be desirable due to the potential for acetate carry over into the water distribution system. Hydrogen has the advantage of low solubility and it is easily removed in a typical water treatment process but it is more expensive than acetate. The ability of the membrane reactor to keep the microbes separated from the treated water may make this process the most desirable despite the fact that the microorganisms are not likely to be pathogenic to humans and that they would be easily removed and inactivated during conventional water treatment.

The technical feasability of these systems is being tested at larger scale. Several systems, including a fixed bed and fluidized bed system, are being tested for treatment of contaminated ground and surface water that is not designated for subsequent potable use. It is planned at the end of 2000, under an AWWARF program, that field tests will be conducted to study the pretreatment of water intended to meet current and anticipated drinking water standards. The system(s) that will be field tested, however, have not yet been specified.

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